mm Universe 2023

Overview of the LiteBIRD space mission

Louise Mousset
on behalf of the LiteBIRD collaboration

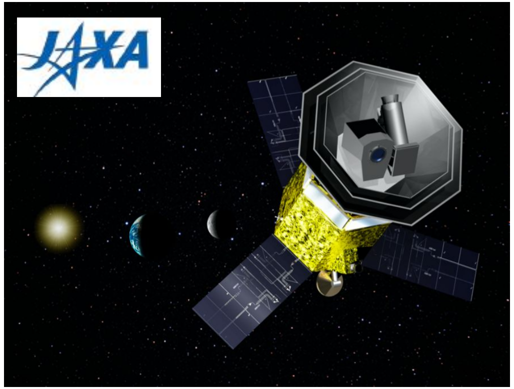
LiteBIRD Mission

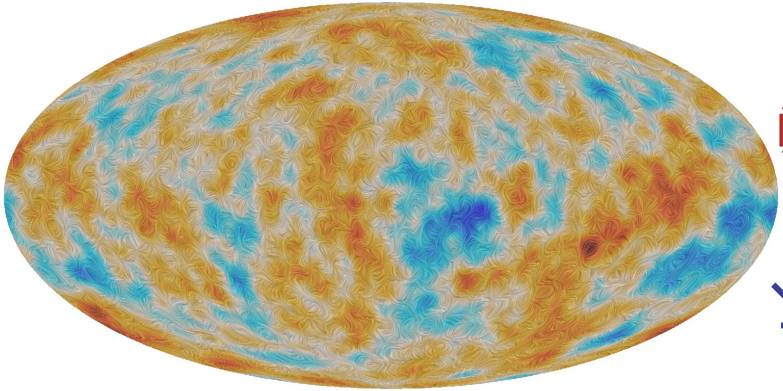
LiteBIRD Mission

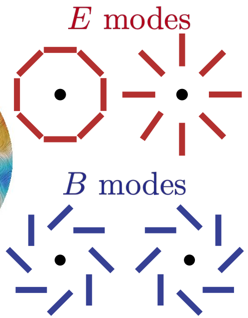
Overview

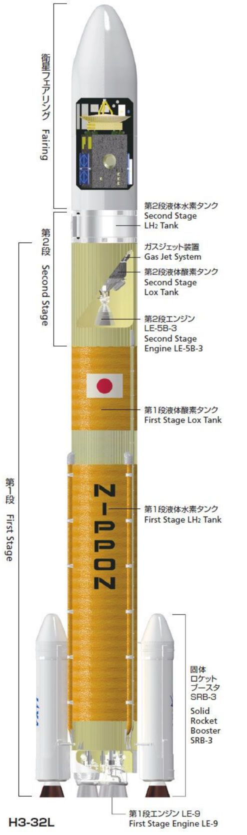
- Lite (Light) satellite for the study of *B*-mode polarization and Inflation from cosmic background Radiation Detection
- JAXA's Strategic Large-class mission selected in May 2019
- Expected launch around 2030 with JAXA's H3 rocket
- All-sky 3-year survey, from Sun-Earth Lagrangian point L2
- Large frequency coverage (40–402 GHz, 15 bands) at 70–18 arcmin angular resolution for precision measurements of the CMB *B*-modes
- Final combined sensitivity: 2.2 μK.arcmin

📖 LiteBIRD Collaboration PTEP 2022









LiteBIRD Mission

The Joint Study Group

Over 350 researchers from **Japan**, **North America** and **Europe**

Team experience in CMB experiments, X-ray satellites and other large projects (ALMA, HEP experiments, …)

LiteBIRD Mission

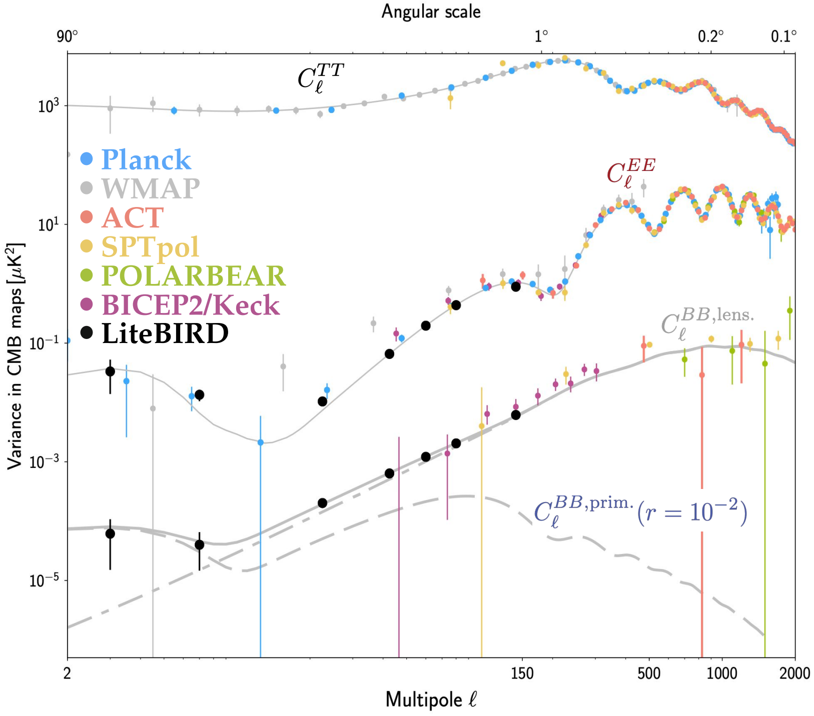
Main Scientific Objectives

- Definitive search for the ***B*-mode signal** from **cosmic inflation** in the CMB polarization
  - Making a discovery or ruling out well-motivated inflationary models
  - Insight into the quantum nature of gravity
- The inflationary (i.e. primordial) *B*-mode power is proportional to the **tensor-to-scalar ratio *r***

- Current best constraint:

  $r < 0.032$ (95% C.L.) Tristram et al. 2021
- LiteBIRD will improve current sensitivity on r by a factor ~50

- Science requirements (no external data):
  - For $r = 0$, **total uncertainty of $\delta r < 0.001$**
  - For $r = 0.01$, 5-σ detection of the reionization ($2 < \ell < 10$) and recombination ($11 < \ell < 200$) peaks independently

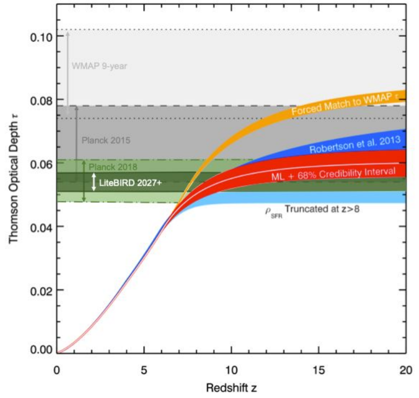


LiteBIRD Mission

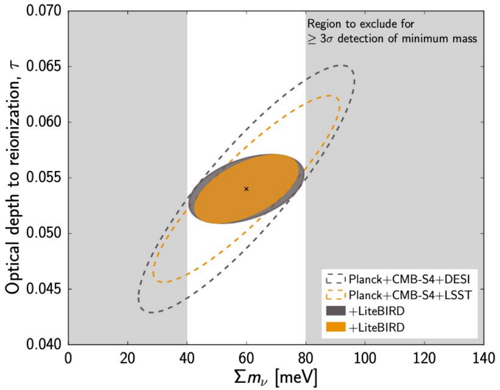
Other Science Outcomes

- The mission specifications are driven by the required sensitivity on *r*
- Meeting those sensitivity requirements would allow us to address other important scientific topics, such as:

1. Characterize the *B*-mode power spectrum and search for source fields (e.g. scale-invariance, non-Gaussianity, parity violation, …)
2. Power spectrum features in polarization
   - Large-scale ***E*-modes**
   - **Reionization**: improve $\sigma(\tau)$ by a factor of 3
   - **Neutrino mass**: $\sigma(\sum m_\nu)$ = 15 meV
3. Constraints on **cosmic birefringence**
4. **SZ effect** (thermal, diffuse, relativistic corrections)
5. **Galactic science**
   - Characterizing the foreground SED
   - Large-scale Galactic magnetic field
   - Models of dust polarization



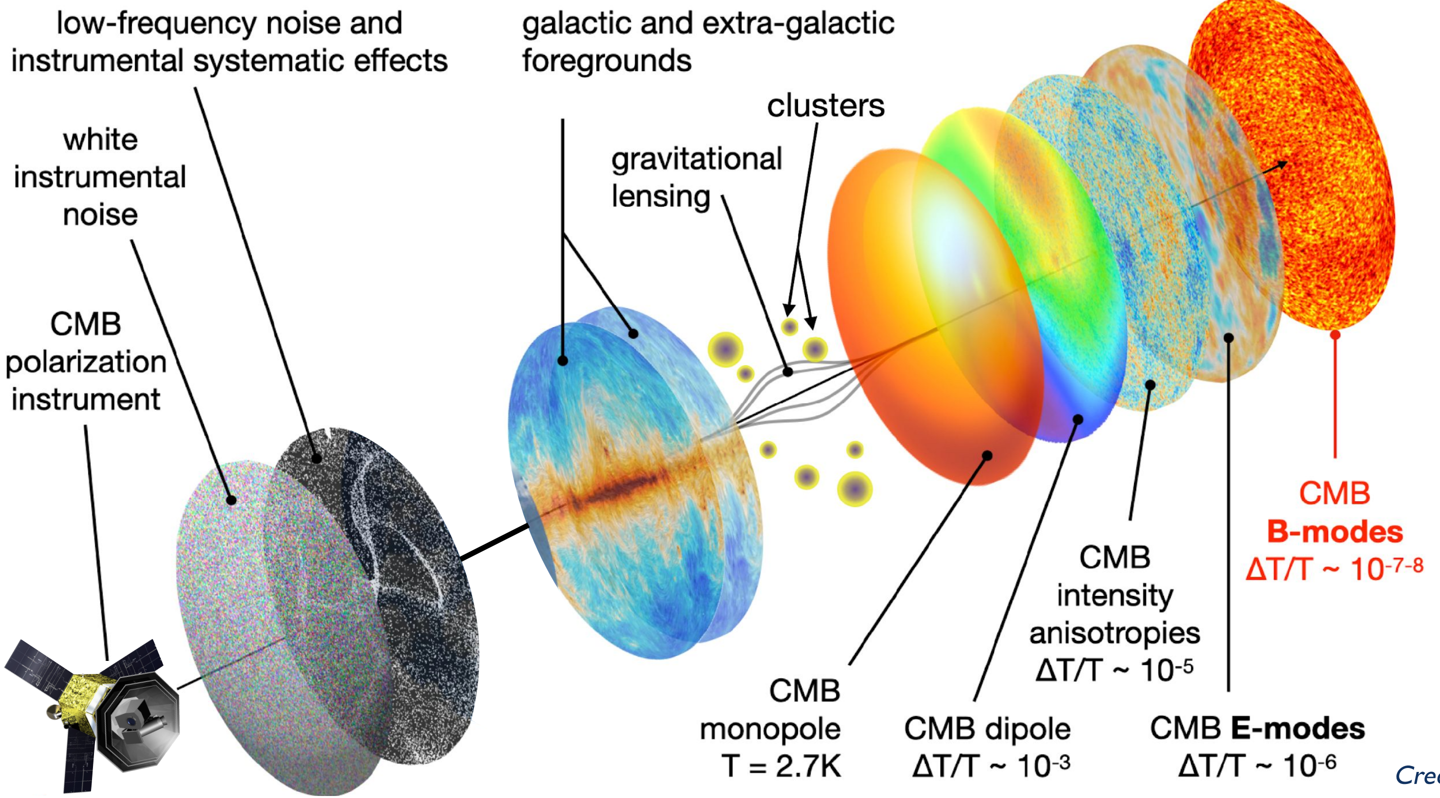
adapted from Robertson+2015



adapted from Calabrese+2017

LiteBIRD Mission

The Challenge of detecting the CMB B-Modes



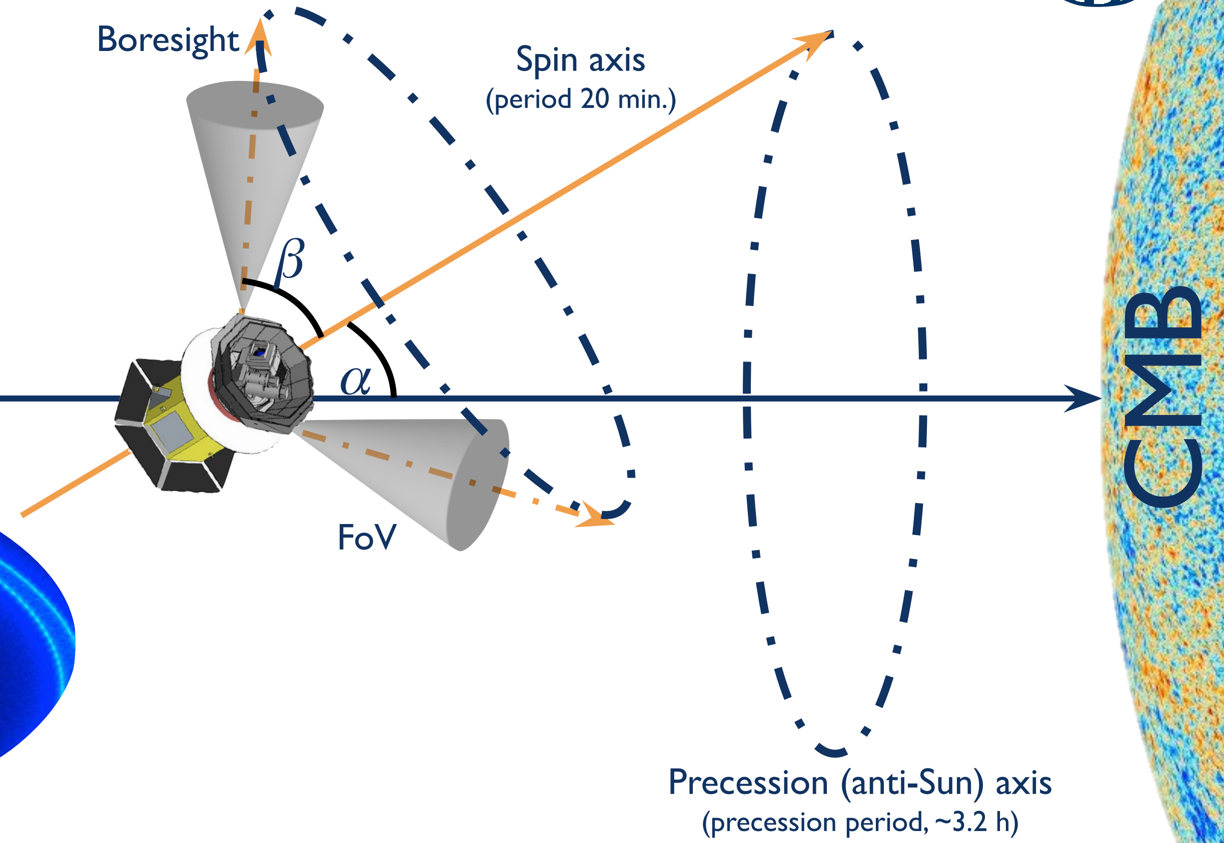
Credit: Josquin Errard

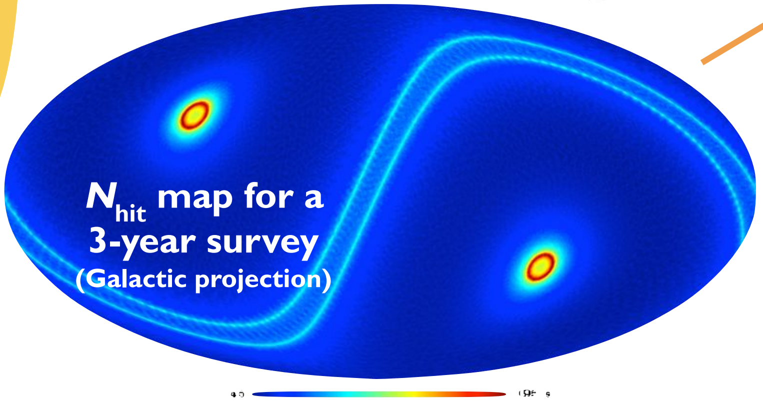
LiteBIRD Design

LiteBIRD Design

Scanning Strategy

- 3-year survey, Sun-Earth L2 Lissajous orbit
- Precession angle: α = 45°
- Spin angle: β = 50°



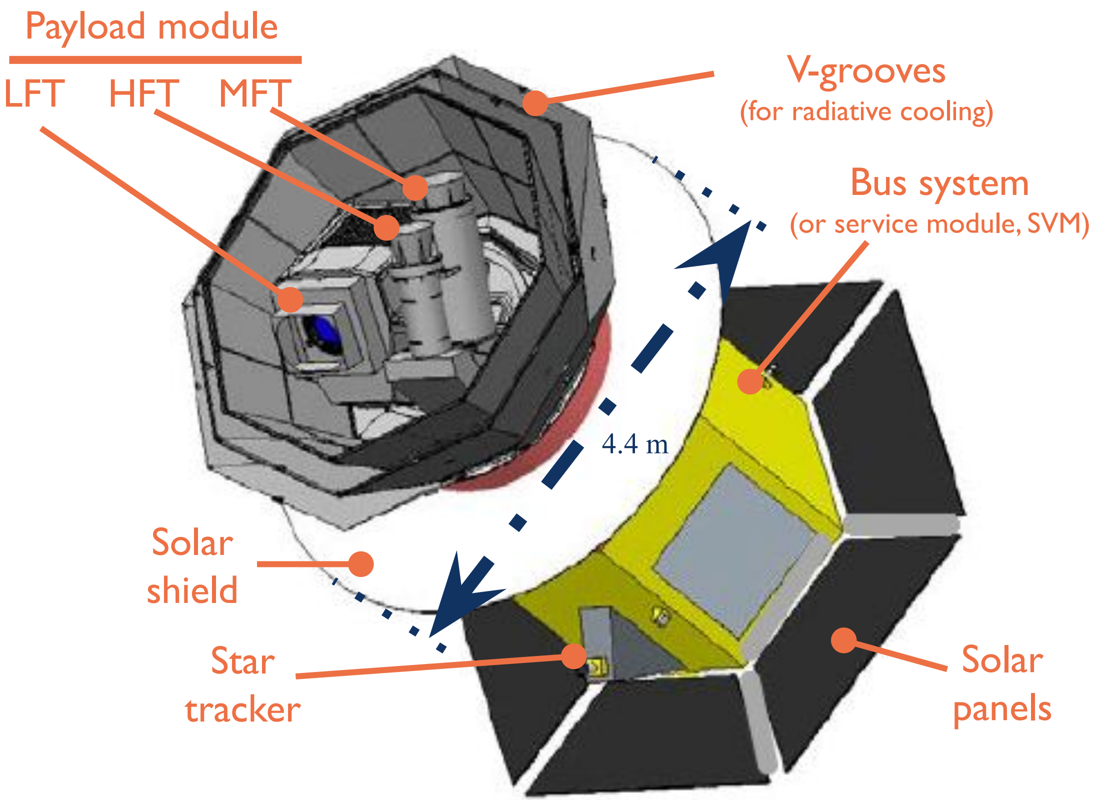


LiteBIRD Design

Spacecraft Overview

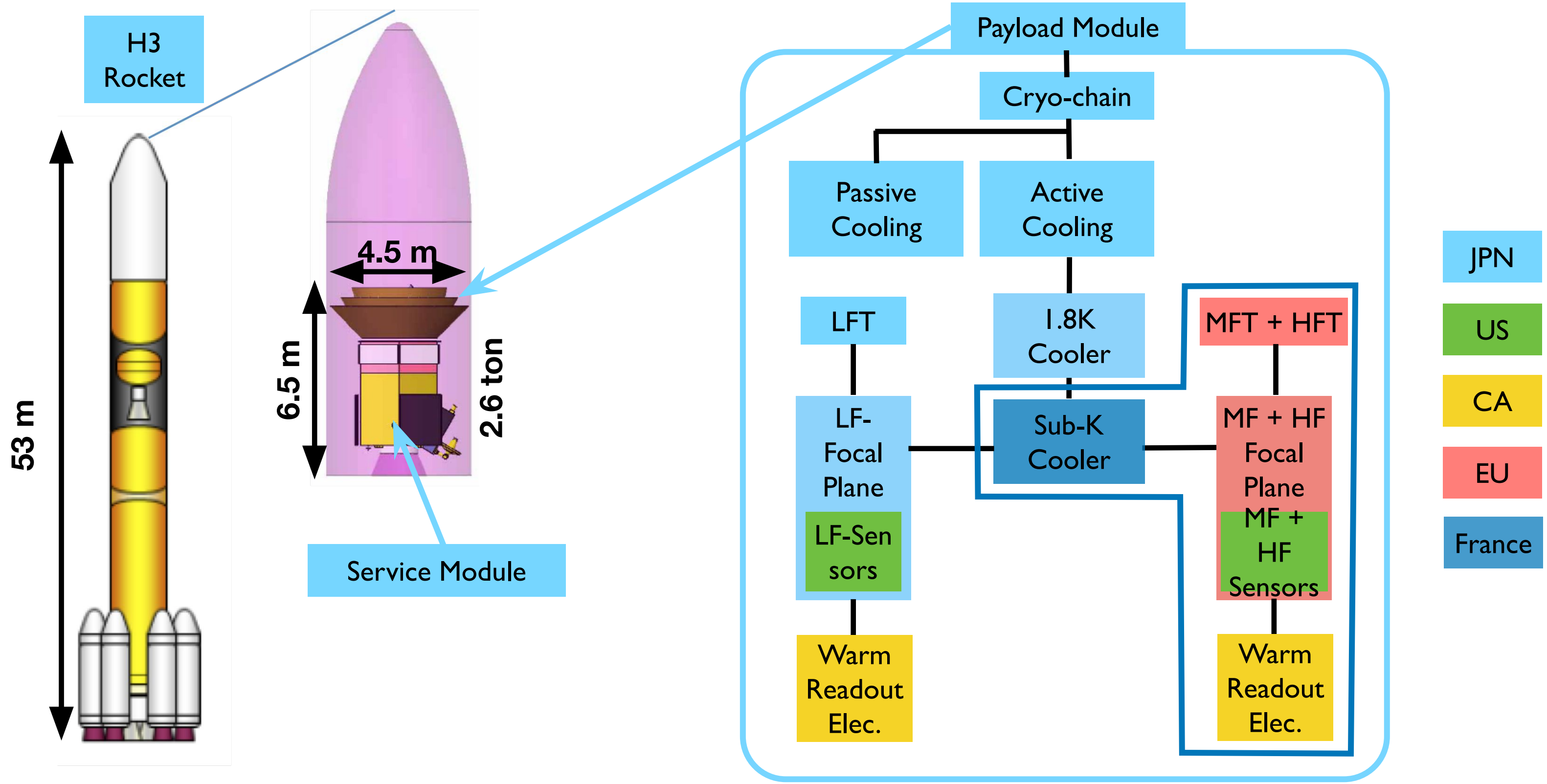
- **3 telescopes** are used to provide the **40-402 GHz** frequency coverage
  1. **LFT** (low frequency telescope)
  2. **MFT** (middle frequency telescope)
  3. **HFT** (high frequency telescope)
- Multi-chroic transition-edge sensor (TES) **bolometer arrays** cooled to **100 mK**
- Polarization modulation unit (PMU) in each telescope with **rotating half-wave plate** (HWP), for 1/*f* noise and systematics reduction
- Optics cooled to **5 K**

> - Mass: 2.6 t
> - Power: 3.0 kW
> - Data: 17.9 Gb/day



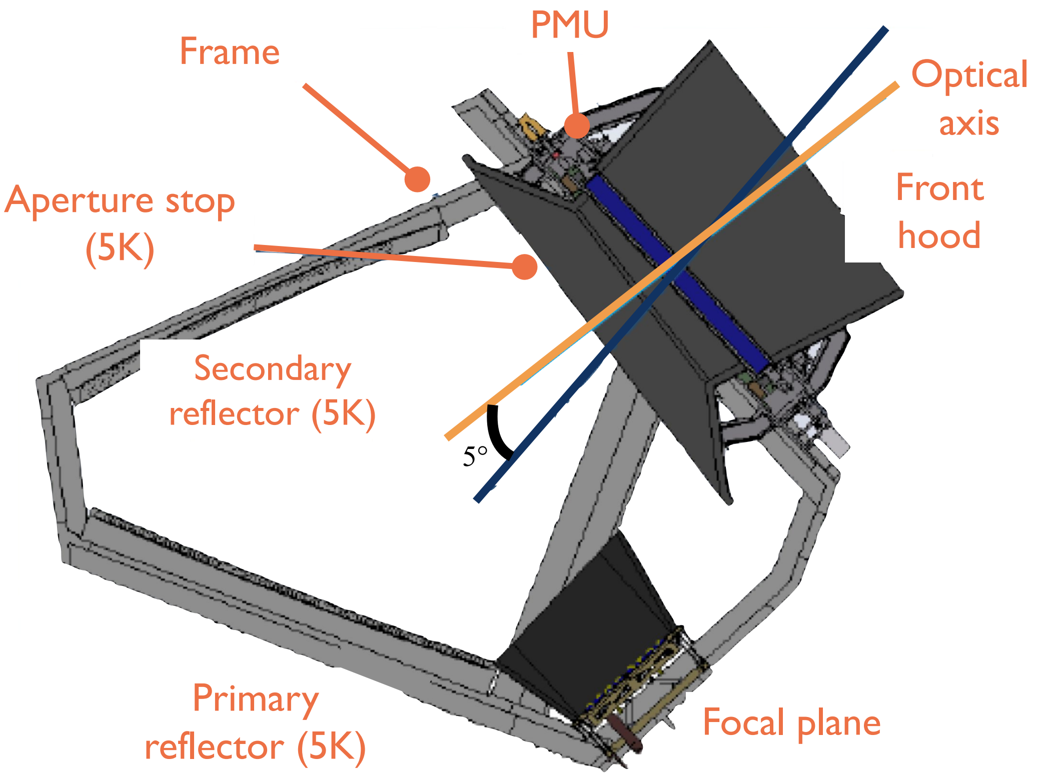
LiteBIRD Design

International Task Sharing



LiteBIRD Design

Low Frequency Telescope (LFT)



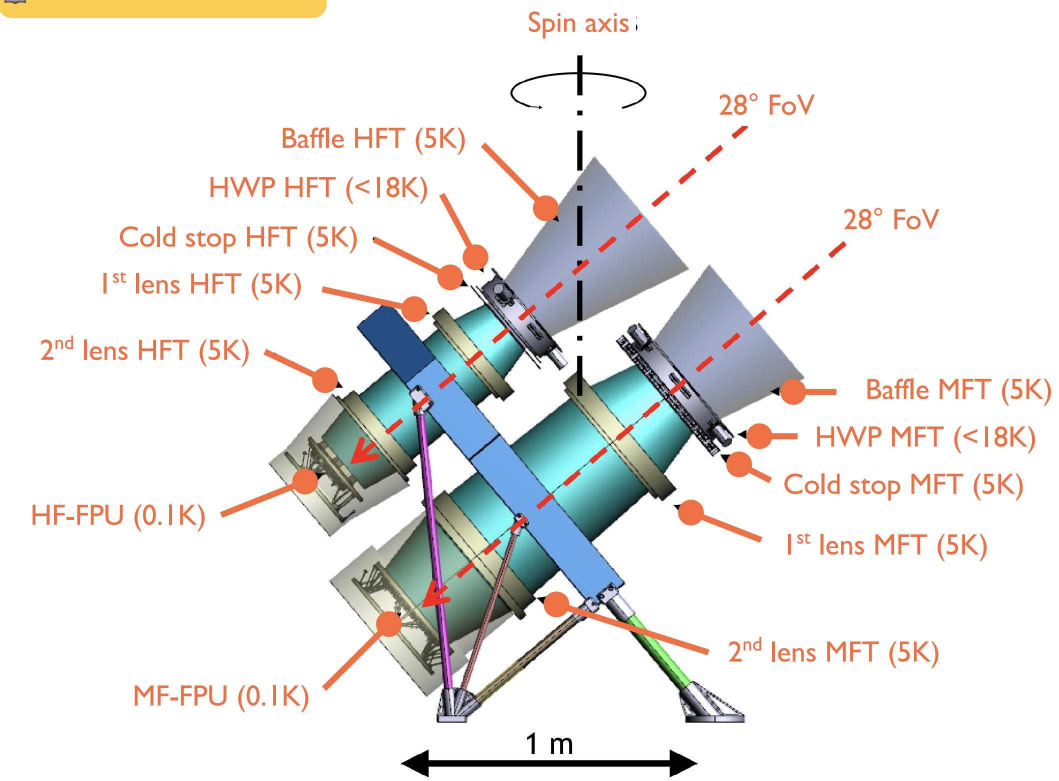
- Polarization Modulation Unit (PMU) as the first sky-side optical element
- **Crossed-Dragone** design
  - Mirrors and aperture stop at **5 K**
  - Made of aluminium
- Field of view: **18°╳9°**
- Strehl ratio > 0.95 (@ 140 GHz)
- Aperture diameter: **400 mm**
- Frequency range: **40-140 GHz**
- Angular resolution: **70-24 arcmin**
- F#3.0 & cross angle of 90°
- Cross-polarization < **-30 dB**
- Rotation of the polarization angle across the FoV < ±1.5°
- Weight < 200 kg

📖 Sekimoto+ SPIE 2020

LiteBIRD Design

Lamagna+ SPIE 2020

Mid-High Frequency Telescopes (MFT / HFT)



- Refractive optics
- Each telescope has PMU with a half-wave-plate (HWP)
- Optics at **5 K**
- Field of view: **28°**
- Simple and high heritage from ground experiments
- Compact (mass & volume)
- Simplified design for filtering scheme
- PP lenses + ARC
- Weight 180 kg

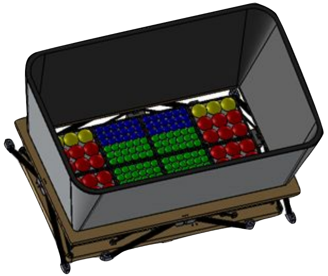
	MFT	HFT
ν (GHz)	100-195	195-402
Ap. diameter (mm)	300	200
Ang. res. (arcmin)	38-28	29-18

LiteBIRD Design

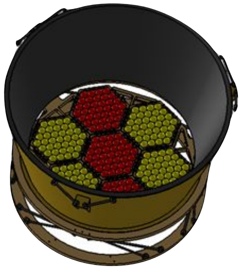
Focal Plane Configuration

- Transision-Edge Sensor (TES) arrays
- Multichroic detectors
- Number of sensors: 4508
- 15 bands including overlap between instruments

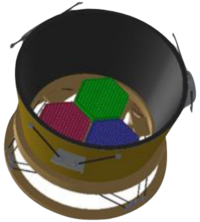
LFT



MFT

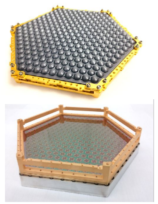


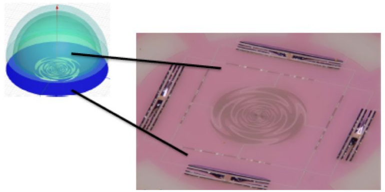
HFT



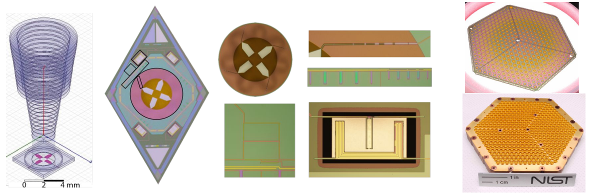
Rule of thumb:
1000 detectors in space = 100 000 detectors on ground

Lensed coupled detectors
Lenslets





Horn coupled detectors
Platelets



Westbrook+ SPIE 2020

MFT (2.5:1)
89GHz — 225 GHz
2075 detectors
366 Trichroic TES
588 Dichroic TES
100 | 119 | 140 | 166 | 195

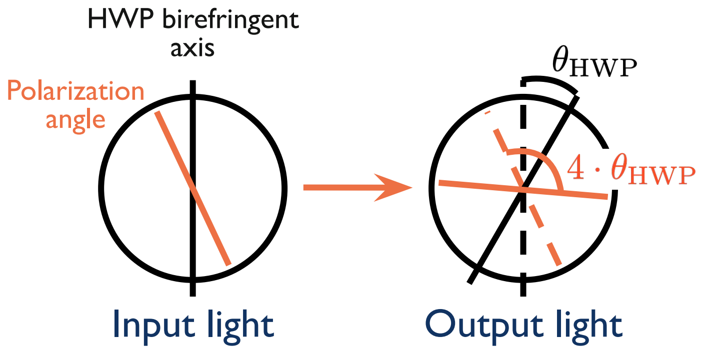
LFT (5.7:1)
34GHz — 161 GHz
40 | 50 | 60 | 68 | 78 | 89 | 100 | 119 | 140
68 | 78 | 89
1258 detectors
2 x (65 + 155) Trichroic TES

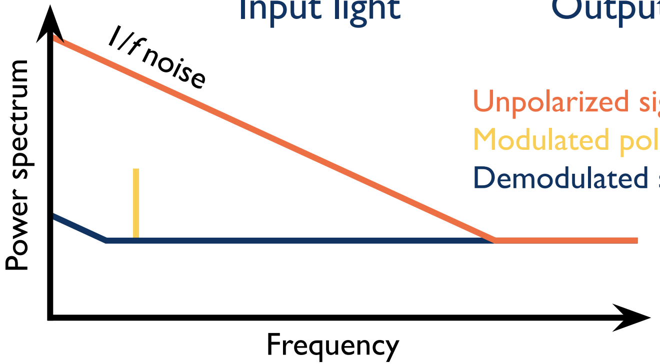
HFT (2.7:1)
166 GHz — 448 GHz
195 | 235 | 280 | 337 | 402
1355 detectors
2 x 255 Dichroic TES
338 Monochromatic TES

LiteBIRD Design

Polarisation Modulation Unit (PMU)

- Rotating a birefringent plate to modulate polarization
- The first sky-side optical element

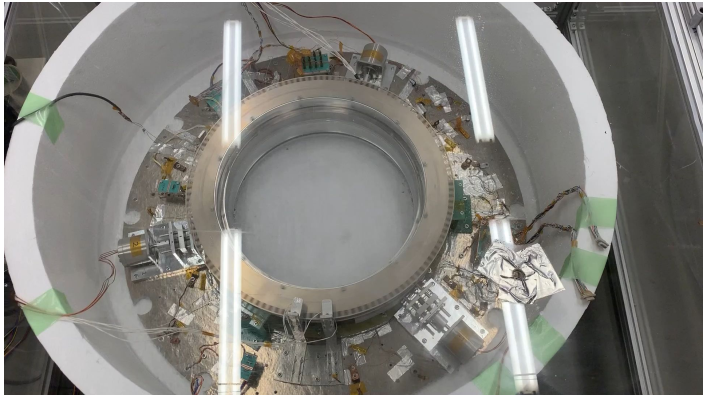




Sakurai+2020 | Komatsu+2020

Toda+2020 | Columbro+2020 | Sugiyama+2020

- LFT PMU BBM at Kavli IPMU:

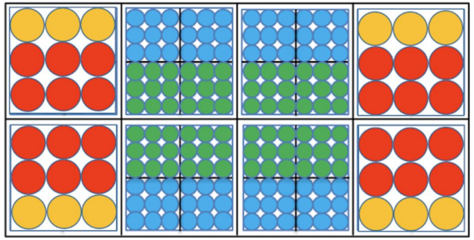


- Rotation test of superconducting magnetic bearing system in the 4K cryostat
- Stable rotation at cryogenic temperature (< 10 K)

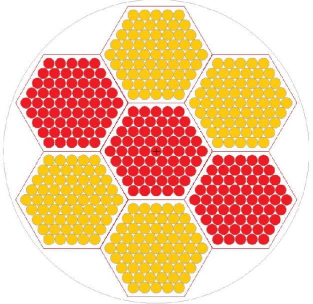
LiteBIRD Forecasts

LiteBIRD Forecasts

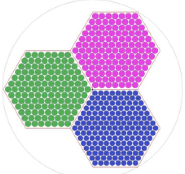
LFT



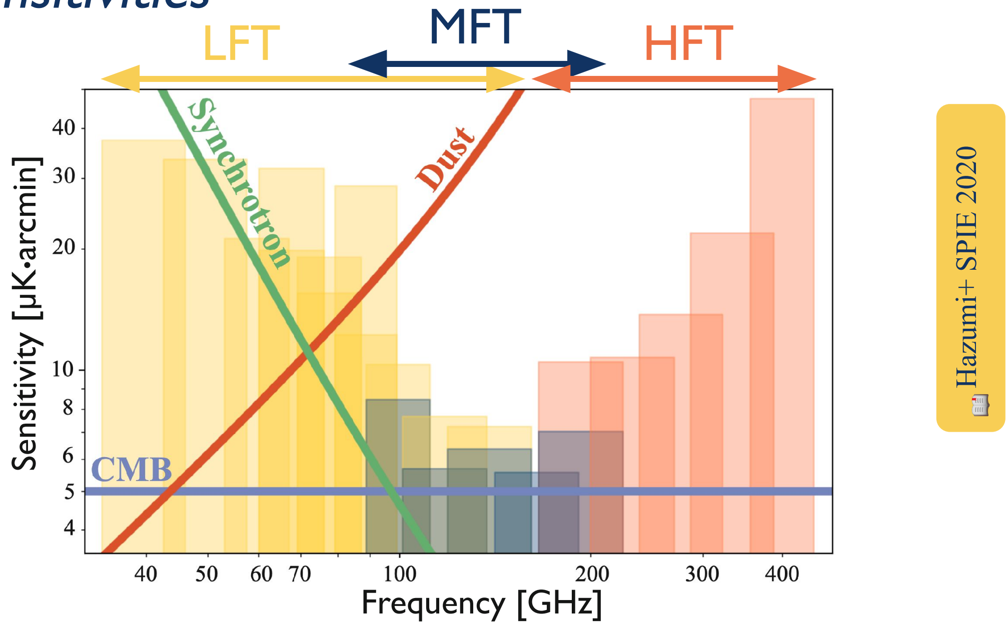
MFT



HFT



Sensitivities

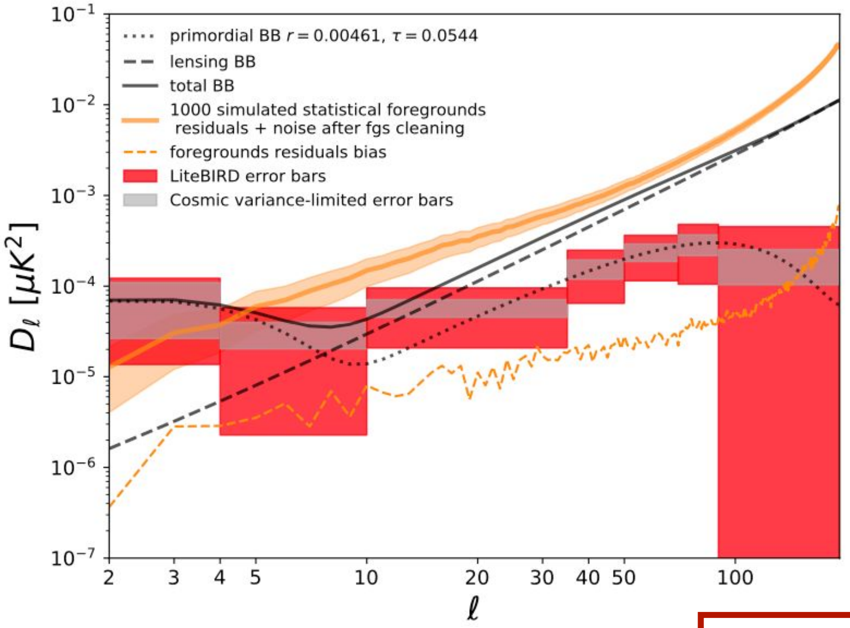


- Projected **polarization sensitivities** for a **3-year full-sky survey**
- Best of 4.3 μK arcmin @ 119 GHz (Hazumi+ 2020)
- Combined sensitivity to primordial CMB anisotropies : **2.2 μK arcmin**

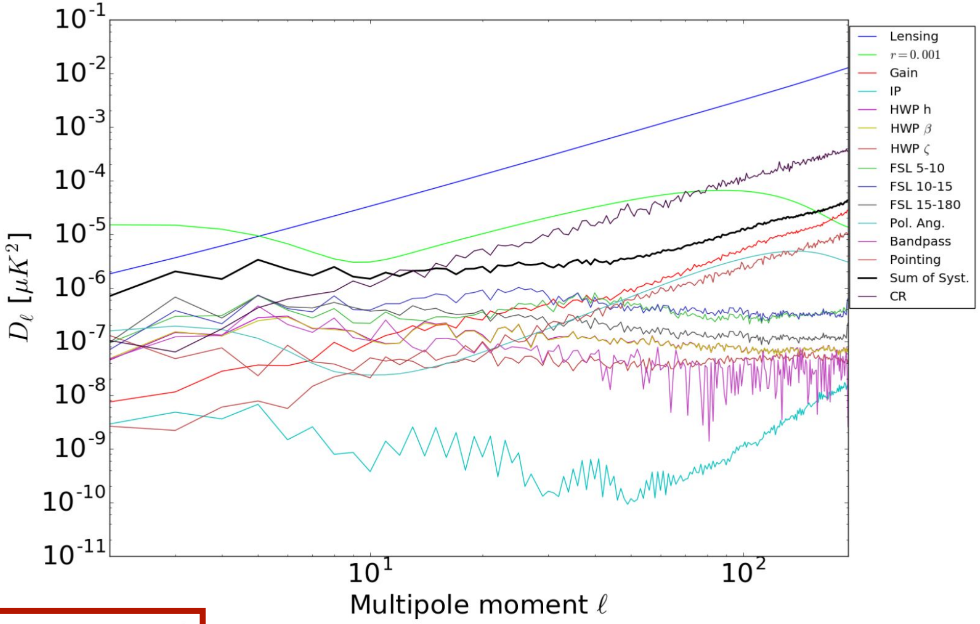
LiteBIRD Forecasts

Impact of Foregrounds and Systematics

Foregrounds



Instrumental Systematics

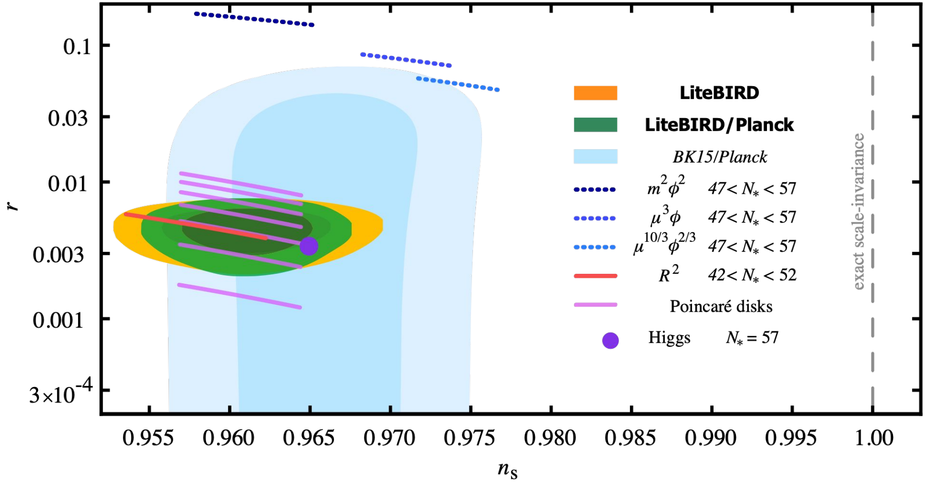


$$\boxed{\delta r = 1.0 \times 10^{-3}}$$

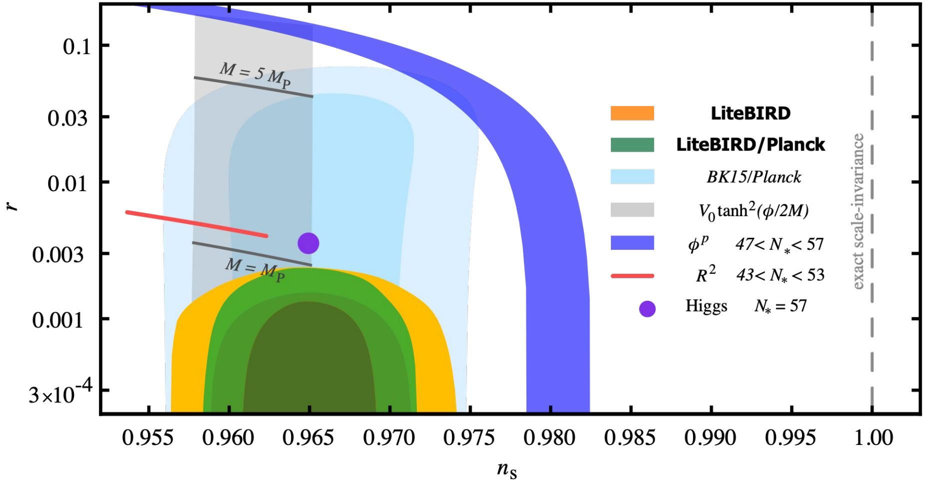
LiteBIRD Forecasts

Inflation Models

Discriminate between well known inflation models in case of detection



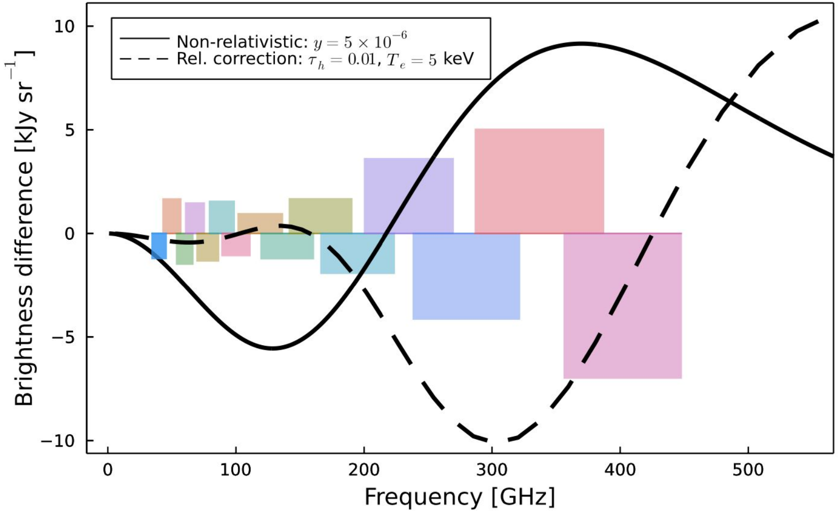
Rejection of large class of models in case of no detection



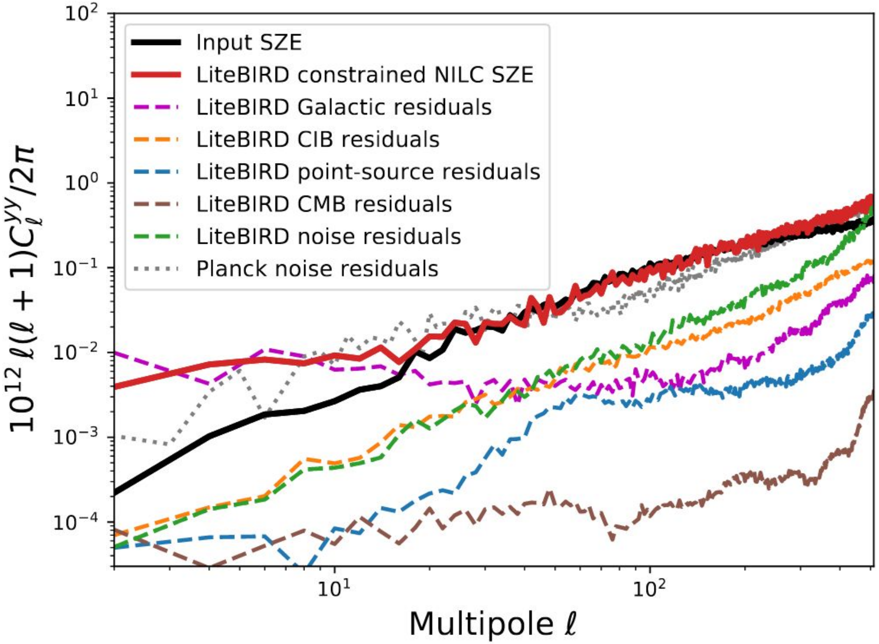
LiteBIRD Forecasts

Thermal SZ

Spectrum of the tSZ effect compared to LiteBIRD sensitivities



Reconstructed power spectrum of the tSZ effect



Summary

The most-mature CMB space mission in 2020's

Phase-A started in Japan, US, CA and EU

Selected by ISAS / JAXA in May 2019

Launch around 2030

Expected sensitivity on r

Full Success:

$$\delta r < 1 \times 10^{-3} (r = 0)$$

$$2 \leq \ell \leq 200$$

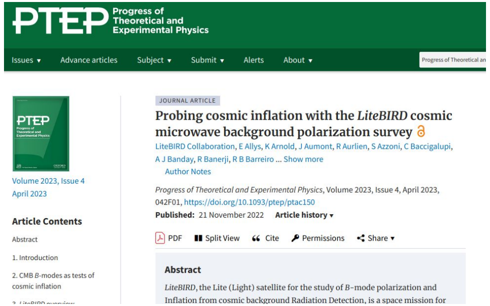
Including statistical noise, systematic effects and component separation

Without de-lensing !

Could gain a factor of about 2 or more when combining with other data

With de-lensing

Review paper


PTEP Progress of Theoretical and Experimental Physics

Issues ▾ Advance articles Subject ▾ Submit ▾ Alerts About ▾

Volume 2023, Issue 4
April 2023

Article Contents

Abstract

1. Introduction

2. CMB B-modes as tests of cosmic inflation

JOURNAL ARTICLE

Probing cosmic inflation with the *LiteBIRD* cosmic microwave background polarization survey

LiteBIRD Collaboration, E Allys, K Arnold, J Aumont, R Aurlien, S Azzoni, C Baccigalupi, A J Banday, R Banerji, R B Barreiro ... Show more

Author Notes

Progress of Theoretical and Experimental Physics, Volume 2023, Issue 4, April 2023, 042F01, https://doi.org/10.1093/ptep/ptac150

Published: 21 November 2022 **Article history** ▾

PDF Split View Cite Permissions Share ▾

Abstract

LiteBIRD, the Lite (Light) satellite for the study of B-mode polarization and Inflation from cosmic background Radiation Detection, is a space mission for

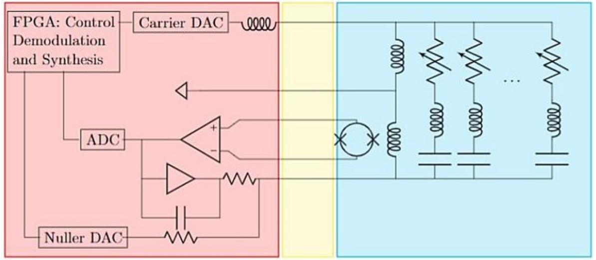
https://academic.oup.com/ptep/article/2023/4/042F01/6835420

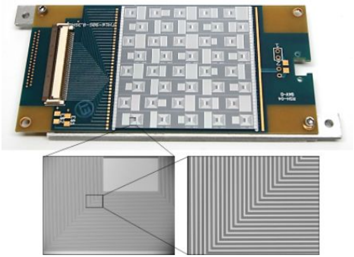
Thank you for your attention!

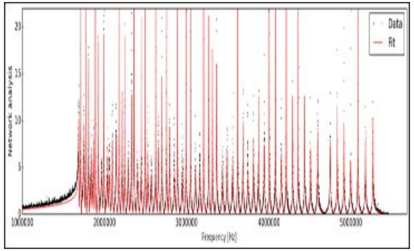
Back-up

LiteBIRD Design

Readout System







Cold Readout LC filters for MUX

- Frequency multiplexing readout technology to readout multiple TES with less components
- Assign unique frequency channel to TES sensors via superconducting resonators
- Low noise SQUID amplifier and FPGA controller readout the signal
- Saves mass, volume, power consumption and cost
- Heritage from ground based CMB experiments

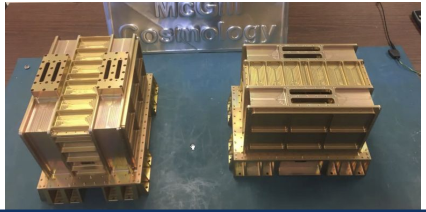
SQUID controller board

SQUID controller assembly

Digitizer assembly

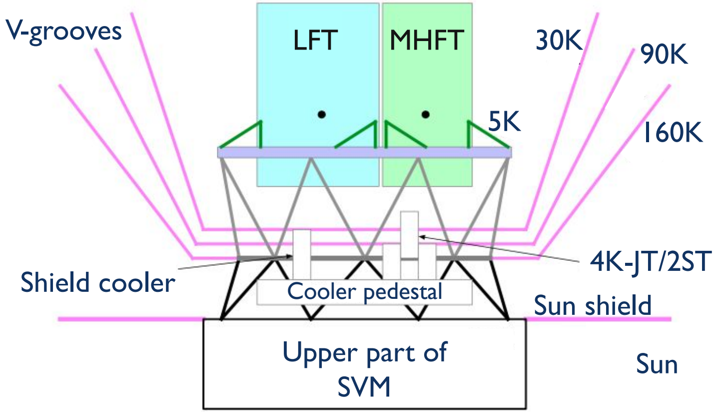
Signal Processing Unit

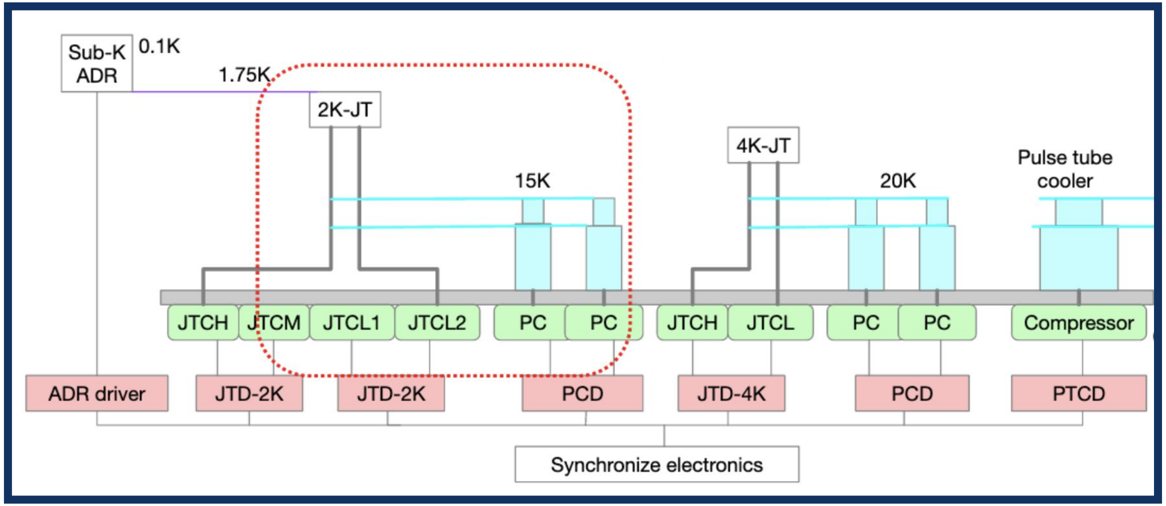
Digitizer assembly



LiteBIRD Design

Cryogenic Chain





Continuous cooling at 100mK

High stability on telescopes at all stages

LiteBIRD Forecasts

Foreground Cleaning

Foregrounds modeling

- Synchrotron:

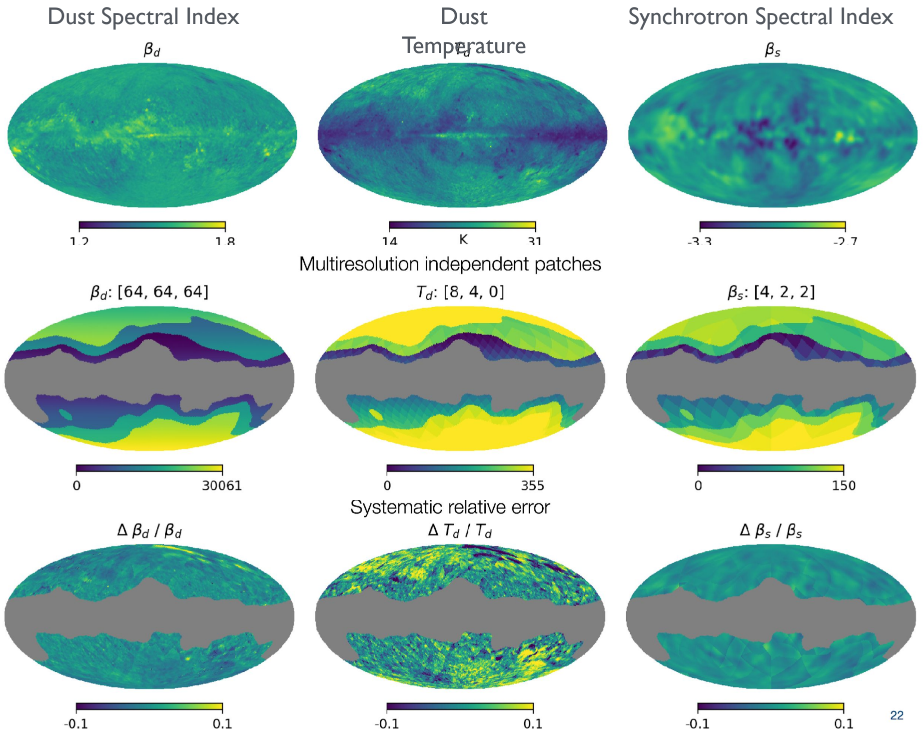
$$[Q_\mathrm{s}, U_\mathrm{s}](\hat{n}, \nu) = [Q_\mathrm{s}, U_\mathrm{s}](\hat{n}, \nu_\star) \cdot \left(\frac{\nu}{\nu_\star}\right)^{\beta_\mathrm{s}(\hat{n})}$$

- Dust: modified blackbody

$$[Q_\mathrm{d}, U_\mathrm{d}](\hat{n}, \nu) = [Q_\mathrm{d}, U_\mathrm{d}](\hat{n}, \nu_\star) \cdot \left(\frac{\nu}{\nu_\star}\right)^{\beta_\mathrm{d}(\hat{n})-2} \frac{B_\nu(T_\mathrm{d}(\hat{n}))}{B_{\nu_\star}(T_\mathrm{d}(\hat{n}))}$$

- "Multiresolution technique" (extension of xForecast), to account for spatial variability.
- => Adapt resolution on each patch for each parameter

Resolution	Fit	S/N	
High	Local	Low	→ Statistical Noise
Low	Global	High	→ Systematics Noise



LiteBIRD Forecasts

Neutrino mass

Improvement of Optical depth determination:

$\sigma(\Sigma m_\nu)$ = 15 meV

Determination of neutrino hierarchy (normal versus inverted)

Measurement of minimum mass
≥ 3σ detection NH ≥ 5σ detection IH

$\sum m_\nu > 0.06\,\mathrm{eV}$ $\sum m_\nu > 0.10\,\mathrm{eV}$